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Dated 29 May 2003

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Request for grant of a patent

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1.	Your reference	P3318.A4/ADS
		29JUL02 E736616-2 D01070 P01/7700 0.00-0217422.5
2.	Patent application number (The Patent Office will fill in this part)	0217422.5 29 JUL 2002
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	Visteon Global Technologies, Inc. Suite 728, Parklane Towers East One Parklane Boulevard Dearborn, MI 48126-2490 United States of America
	Patents ADP number *(if you know it)*	7940307001
	If the applicant is a corporate body, give the country/state of its incorporation	United States of America, State of Michigan
4.	Title of the invention	Open Loop Fuel Controller
5.	Name of your agent *(if you have one)*	DUMMETT COPP
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	25 THE SQUARE MARTLESHAM HEATH IPSWICH IP5 3SL
	Patents ADP number *(if you know it)*	6379001
6.	If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	Country / Priority application number *(if you know it)* / Date of filing *(day / month / year)*
7.	If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application / Date of filing *(day / month / year)*
8.	Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body.* *See note (d))*	YES

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Continuation sheets of this form	
Description	13
Claim*(s)*	4
Abstract	1
Drawing*(s)*	5

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translation of priority documents	/
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	TWO
Request for preliminary examination and search *(Patents Form 9/77)*	ONE
Request for substantive examination *(Patents Form 10/77)*	ONE
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Dummett Copp

Signature: DUMMETT COPP

Date: 26 July 2002

12. Name and daytime telephone number of person to contact in the United Kingdom: Alison Simons 01473 660600

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Statement of inventorship and of right to grant of a patent

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Cardiff Road
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1.	Your reference	P3318.A4/ADS
2.	Patent application number 0217422.5	29 JUL 2002
3.	Full name of the or of each applicant	Visteon Global Technologies, Inc.
4.	Title of the invention	Open Loop Fuel Controller
5.	State how the applicant*(s)* derived the right from the inventor*(s)* to be granted a patent	BY VIRTUE OF THE EMPLOYMENT OF THE INVENTOR(S) BY VISTEON UK LIMITED AND BY VIRTUE OF AN AGREEMENT BETWEEN VISTEON UK LIMITED AND VISTEON GLOBAL TECHNOLOGIES, INC. DATED 28.6.00.
6.	How many, if any, additional Patents Forms 7/77 are attached to this form *(see note (c))*	ONE
7.	Dummett Copp	I/We believe that the person*(s)* named over the page *(and on any extra copies of this form)* is/are the inventor*(s)* of the invention which the above patent application relates to. Signature: DUMMETT COPP Date: 26 July 2002
8.	Name and daytime telephone number of person to contact in the United Kingdom	Alison Simons 01473 660600

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Enter the full name, address and postcodes of the inventors in the boxes and underline the surnames

Mark Paul Guerrier 21 Bader Walk Northfleet Gravesend Kent, DA11 8PU United Kingdom 8434391001
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Reminder

Have you signed the form?

OPEN LOOP FUEL CONTROLLER

This invention relates to a method and apparatus for controlling the air-fuel ratio demanded by a fuel controller in order to maintain optimum performance of a catalytic converter where there is no feed back between the achieved air fuel ratio and the desired air fuel ratio.

Three way catalytic converters are used to reduce exhaust emission of nitrous oxides (NO_x) hydrocarbon (HC) and carbon monoxide (CO). In a steady sate of operation the performance of the catalyst in removing these pollutants is at an optimum level when the air fuel ratio of the exhaust gas is within a narrow range, close to the stoichiometric air-fuel ratio.

Conventionally, a fuel controller is used to control the air fuel ratio demand from an engine based on feedback from an air fuel ratio sensor upstream of a catalytic converter in the exhaust passage or from two air fuel ratio sensors, one upstream of the catalytic converter, and one downstream of the catalytic converter. Operation based on such feedback is known as 'closed-loop' operation.

However, when it is desired to operate the engine away from the stoichiometric, as the air fuel sensors are insensitive to changes in the air fuel ratio other than around the stoichiometric air fuel ratio, there is no feed back correction relating to the air-fuel ratio actually achieved. Such operation is known as 'open-loop' operation.

For example, after throttle opening it may be desirable to operate on the rich side of a stoichiometric air fuel ratio

in order to provide extra torque. Another example is after deceleration fuel shut off it may be desirable to operate on the rich side of a stoichiometric air fuel ratio in order to regenerate the catalyst.

The problem therefore is that when an engine is operating away from stoichiometric it is in open loop operation and any error between the requested air fuel ratio and the achieved air fuel ratio is not corrected.

The object of this invention is to provide a method and apparatus for correcting air fuel ratio errors when in open-loop operation when the engine is operating with a substantially different air fuel ratio to that which is stoichiometric.

According to the present invention there is provided an open loop air fuel ratio controller comprising a detector arranged down stream of a catalyst for detecting rich breakthrough; a catalyst model having an estimator for estimating a stored oxygen level in the catalyst; a comparator for comparing an estimated stored oxygen level with a plurality of predetermined thresholds; demand adjusting means for adjusting an air fuel ratio demand in dependence upon a received signal from said comparator and upon a received signal from said detector.

This provide means for adjusting the air fuel ratio by using the estimated stored oxygen level as well as an indication of whether rich breakthrough has yet occurred.

It is an advantage of the controller further comprises model

adjusting means for adjusting the model in dependence upon a received signal from said comparator and upon a received signal from said detector so that the model may also be adjusted, for example if characteristics of the catalyst change due to ageing.

If the comparator is arranged to compare an estimated stored oxygen level with a plurality of thresholds when the detector detects rich breakthrough then different actions may be taken in dependence upon the estimated stored oxygen level falling within various ranges when rich breakthrough is detected.

Preferably either the model is adjusted or the air fuel ratio demand is adjusted in particular circumstances, but not both. Therefore preferably the controller is arranged such that when the model adjusting means adjusts the model the demand adjusting means does not adjust the air fuel ratio demand. Furthermore, the controller is arranged such that when the demand adjusting means adjusts the air fuel ratio demand the model adjusting means does not adjust the model.

In a preferred embodiment the model adjusting means is arranged to adjust the model to reduce or increase a maximum oxygen storage value and the detector is a heated exhaust gas oxygen sensor.

According to another aspect of the invention there is also provided a method of open loop fuel control comprising the steps of detecting rich breakthrough downstream of a catalyst; estimating an oxygen storage level in the catalyst; comparing the estimated oxygen storage level with a plurality

of predetermined thresholds; and adjusting the air fuel ratio demand in dependence upon the results of said comparing step and said detecting step.

It is an advantage if the method further comprises the step of adjusting the model in dependence upon the results of said comparing step and said detecting step.

Preferably, if the estimated oxygen storage level is less than a first predetermined threshold then the air fuel ratio demand is adjusted in a rich direction.

In a preferred embodiment there is a range of values within which the estimated oxygen storage level is expected to fall when a rich breakthrough is detected, and therefore not action is taken. Accordingly in this embodiment the model adjusting step and the air fuel ratio demand adjusting step are not performed if a rich breakthrough is detected and if the estimated oxygen level is greater than a second predetermined threshold and less than a third predetermined threshold.

Preferably adjusting the air fuel ratio demand comprises the sub step of determining whether the estimated oxygen storage level is greater than a fourth predetermined threshold when a rich breakthrough is detected, if so then the air fuel ratio demand is adjusted in a lean direction.

Preferably the model adjusting step is arranged to adjust the model such that a maximum value for the oxygen storage level is increased if a rich breakthrough is detected and if the estimated oxygen level is between the first predetermined

threshold and the second predetermined threshold.

It follows that, preferably the model adjusting step is also arranged to adjust the model such that a maximum value for the oxygen storage level is decreased if a rich breakthrough is detected and if the estimated oxygen level between the third predetermined threshold and the fourth predetermined threshold.

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which

Figure 1 is a block diagram illustrating use of a catalyst observer model;
Figure 2 is a graph showing the difference in operation between a new catalyst, and one which has deteriorated;
Figure 3 is a graph showing how catalyst characteristics change with age of the catalyst;
Figure 4 illustrates a range of estimated oxygen storage values with predetermined thresholds indicated therein; and
Figure 5 is a flow chart sowing the method steps carried out in an open loop fuel controller of the present invention.

Referring now to Figure 1, a model 1 of a catalyst 2 will be described. An air flow sensor 4 mounted in an intake pipe of an engine 3 is used to measure air mass flow induced by the engine 3. In other embodiments of the invention the air mass flow may be estimated from other parameters, for example

manifold pressure, engine speed and air temperature.

Exhaust gases from the engine 3 are fed to the catalyst 2 mounted in an exhaust pipe. A sensor 7 measures the air fuel ratio downstream of the catalyst 2. The sensor 7 may be a Universal Exhaust Gas Oxygen (UEGO) sensor or may be a Heated Exhaust Gas Oxygen (HEGO) sensor. A HEGO sensor senses whether the air-fuel ratio is rich or lean of stoichiometric, whereas a UEGO sensor provides a measurement of the air fuel ratio. A sensor 8 measures the temperature of the catalyst 2. The catalyst 2 does not perform well at low temperatures so the model 1 has the measured catalyst temperature as an input, and does not operate until the temperature of the catalyst reaches a minimum temperature. In other embodiments the catalyst temperature may be estimated using a catalyst model.

The observer model 1 operates as will now be described, although the invention is not limited to use of this particular model, and simpler or more complex catalyst models could be utilised.

Oxygen storage of the catalyst is represented by an oxygen storage variable ϕ which is equal to zero when the catalyst is in a neutral state, is negative if the catalyst is depleted of oxygen and is positive if the catalyst is oxygen rich. It is possible to measure the air fuel ratio upstream of the catalyst 2 by use of a UEGO. However, use of a UEGO is costly, and even a UEGO has a limited range around stoichiometric within which the air fuel ratio measurement is accurate. Therefore the model used assumes that the

precatalyst air fuel ratio λ_{precat} is equal to the air fuel ratio demanded by a control system (not shown). Therefore the model 1 has as an input an air fuel ratio demand which is received from the control system.

The rate of change of the oxygen storage variable ϕ is estimated according to the following equation.

$$d\phi/dt = (\Delta\lambda_{precat} - N(\phi)S_{wv}) * \text{oxygen\_mass}/\lambda_{precat}$$

$\Delta\lambda_{precat}$ is equal to $\lambda_{precat}-1$, therefore $\Delta\lambda_{precat}$ is negative if the air fuel ratio is rich of stoichiometric, and $\Delta\lambda_{precat}$ is positive if the air fuel ratio is lean of stoichiometric. The air mass flow measured at the sensor 4 is multiplied by a constant value 0.21 which is equal to the fraction of air by mass which is oxygen, this fraction is denoted oxygen_mass in the above equation.

$N(\phi) = \Sigma a_i\phi^i$ and represents the resistance to oxygen storage of the catalyst for a particular value of ϕ as illustrated in Figure 2.

S_{wv} is equal to 0 when $\Delta\lambda_{precat}$ is negative i.e. the air fuel ratio is rich of stoichiometric and ϕ is greater than 0 i.e. there is excess oxygen stored in the catalyst.

It will be understood that when a rich air fuel ratio is supplied to the engine 3, and when there is excess oxygen stored in the catalyst 2, then the engine 3 emits gaseous components which can be oxidised by the catalyst 2, and in this case S_{wv} is equal to 0 so that

$$d\phi/dt = \Delta\lambda_{precat} * oxygen\_mass/\lambda_{precat}$$

However, when a lean air fuel ratio is supplied to the engine 3 or when the catalyst 2 is depleted of oxygen then S_{wv} is equal to 1 so that

$$d\phi/dt = (\Delta\lambda_{precat} - N(\phi)) * oxygen\_mass/\lambda_{precat}$$

so in this case $d\phi/dt$ is reduced by an amount equal to $N(\phi) * oxygen\_mass/\lambda_{precat}$ when compared to the previous case.

$$Est(\lambda_{postcat}) = N(\phi) S_{wv} + 1.$$

$\lambda_{postcat}$ is the downstream air fuel ratio divided by the stoichiometric air fuel ratio. ϕ is calculated by integrating the above differential equation, and then $N(\phi)$ is calculated. When $S_{wv} = 0$ then $Est(\lambda_{postcat}) = 1$, otherwise $Est(\lambda_{postcat}) = N(\phi) + 1$.

$Est(\lambda_{postcat})$ and the measured $\lambda_{postcat}$ may be compared if the sensor 7 is a UEGO, and the difference between them may be used to update the coefficients a_i of the oxygen storage characteristic curve $N(\phi)$ and the ϕ value itself so that the model 1 more accurately represents the performance of the catalyst 2. The coefficients a_i may be updated using a Kalman filter, a description of which may be found in "Applied Optimal Estimation", Gelb, the MIT press 1974. If the sensor 7 is a HEGO then it is only possible to determine whether $\lambda_{postcat}$ is rich or lean of stoichiometric, and hence it is

only possible to decide whether to increase or reduce the maximum level of ϕ, which may be regarded as the oxygen saturation level.

Figure 2 illustrates the differing $N(\phi)$ curves for a good catalyst compared with a deteriorated catalyst.

After the engine has been operating at a particular air fuel ratio for some time, then the oxygen stored in the catalyst will stabilise at a value which depends upon the operating air-fuel ratio, thus $d\phi/dt = 0$ and

$\Delta\lambda_{precat} = \Delta\lambda_{postcat}$

Figure 3 illustrates an example oxygen storage characteristic curve showing the oxygen storage value when $\Delta\lambda_{precat} = \Delta\lambda_{postcat} = 0.1$ and when $\Delta\lambda_{precat} = \Delta\lambda_{postcat} = -0.1$. Figure 3 illustrates how an oxygen storage characteristic curve may change for a deteriorated catalyst. The difference in the steady state oxygen storage value is illustrated for $\Delta\lambda_{precat} = \Delta\lambda_{postcat} = -0.1$ for two examples of oxygen storage characteristic curves. Hence it will be appreciated that if fuel control is implemented using air fuel ratio thresholds measured at the sensor 7, then as the catalyst deteriorates, the fuel control scheme will allow breakthrough of NO_x when the catalyst resists absorption of any more oxygen, and breakthrough of HC and CO when the catalyst is depleted of oxygen.

It is known to update a catalyst model by detecting unexpected breakthroughs. In particular the model parameters are adjusted such that the maximum level of oxygen storage is adjusted to accommodate aging properties of the catalyst.

However, unexpected breakthrough may also occur when λ_{precat} does not accurately reflect lambda-demand. As explained earlier, use of a wide ranging precatalyst UEGO is not practical so adjusting the lambda demand using feedback is not possible. This invention addresses the problem of open loop fuel control together with updating of a catalyst model as the catalyst characteristics change.

The catalyst characteristics are only likely to change slowly over time, therefore any difference between Est($\lambda_{postcat}$) and the measured $\lambda_{postcat}$ due to catalyst ageing is likely to be within a small range. In this invention it is assumed that differences within a small range are due to catalyst aging and that larger differences are due to errors in the open loop control (i.e. due to differences between lambda-demand and λ_{precat}). The difference between Est($\lambda_{postcat}$) and the measured $\lambda_{postcat}$ is estimated by monitoring ϕ as predicted by the model 1 and detecting rich breakthrough using the sensor 7.

If the catalyst is in a neutral state then we expect ϕ to be equal to 0. If ϕ is less than 0 then we expect rich breakthrough to occur and if ϕ is greater than 0 then we do not expect rich breakthrough to occur (although lean breakthrough might then occur resulting in NO_x emissions)

However, to allow for some tolerance a range may be defined, within which is it expected that ϕ will fall when rich break through occurs. Figure 4 illustrates a range of ϕ values with

predetermined thresholds A, B, C and D indicated therein.

When rich breakthrough is detected the current value of ϕ estimated by the model 1 is used to determine what if any action is to be taken. A first predetermined threshold D is defined, and if ϕ falls below this threshold then rich breakthrough is considered to have occurred very late and the open loop fuel control is adjusted accordingly. A second predetermined threshold C is defined and if ϕ is between the first predetermined threshold D and the second predetermined threshold C then rich breakthrough is considered to have occurred late enough for the model to need to be updated. A third predetermined threshold B is defined and if ϕ falls between the second predetermined threshold C and the third predetermined threshold B when rich breakthrough occurs then this is considered to be within normal limits. Finally a fourth predetermined threshold A is defined and if ϕ is between the third predetermined threshold B and the fourth predetermined threshold A then rich break through is considered to have occurred early enough for the model to need to be updated. If ϕ is greater than the fourth predetermined threshold A then it is considered that rich breakthrough has occurred very early and the open loop fuel control is adjusted accordingly. D <= C <= B <= A, and Figure 4 indicates the conclusion made when ϕ falls within the ranges shown. It will be appreciated that C <= 0 <= B so that rich breakthrough is expected to occur close to ϕ = 0. Also it is with noting that one or more thresholds may be equal to one another, so for example the tolerance range C-B could be set to be equal to 0. Finally it is worth noting that if *no* rich break through is detected and ϕ is less than the first

predetermined threshold D then rich breakthrough is considered to have occurred very late and the open loop fuel control is adjusted accordingly.

Figure 5 illustrates the steps taken by an open loop fuel controller according to one embodiment of the present invention.

If rich breakthrough is detected at the sensor 7 at step 40, then ϕ is compared to the first predetermined threshold D at step 42. If ϕ is less than D then rich breakthrough has occurred very much later than the model 1 predicts. Therefore it is assumed that the error is due to a difference between the lambda demand and the achieved lambda (i.e. λ_{precat}). In this case at step 44 the lambda demand is adjusted to become richer. If ϕ is not less than D at step 42 then ϕ is compared to the second predetermined threshold C at step 46. If ϕ is less than C it is assumed that the error is due to a change in the catalyst characteristics and the catalyst model is adjusted so that the saturation level is increased at step 48.

If ϕ is not less than C at step 46 then ϕ is compared to the third predetermined threshold B at step 50. If ϕ is less than B it is considered that rich break trough has occurred within expected range of ϕ and no action is taken. However, if ϕ is not less than B at step 50 then ϕ is compared to the first predetermined threshold A at step 52.

If ϕ is less than A it is assumed that the error is due to a

change in the catalyst characteristics and the catalyst model is adjusted so that the saturation level is decreased at step 54.

If ϕ is not less than A then rich breakthrough has occurred very much earlier than the model 1 predicts. Therefore it is assumed that the error is due to a difference between the lambda demand and the achieved lambda (i.e. λ_{precat}). In this case at step 56 the lambda demand is adjusted to become leaner.

Lambda demand may be adjusted by means of a data table, which is updated according to the value of ϕ at step 56 or 44 as appropriate, and which is added to the lambda demand as determined by a conventional open loop fuel controller.

If rich breakthrough is not detected at step 40, then at step 58 ϕ is compared to the first predetermined threshold D. If ϕ is less than D then rich breakthrough has occurred very much later than the model 1 predicts. Therefore it is assumed that the error is due to a difference between the lambda demand and the achieved lambda (i.e. λ_{precat}). In this case at step 44 the lambda demand is adjusted to become richer.

It is intended that the foregoing detailed description be regarded as illustrative rather than limiting and that it be understood that it is the following claims, which are intended to define the scope of the invention.

CLAIMS

1. An open loop air fuel ratio controller comprising
a detector arranged down stream of a catalyst for detecting rich breakthrough;
a catalyst model having an estimator for estimating a stored oxygen level in the catalyst;
a comparator for comparing an estimated stored oxygen level with a plurality of predetermined thresholds;
demand adjusting means for adjusting an air fuel ratio demand in dependence upon a received signal from said comparator and upon a received signal from said detector.

2. An open loop air fuel ratio controller according to claim 1, further comprising
model adjusting means for adjusting the model in dependence upon a received signal from said comparator and upon a received signal from said detector.

3. An open loop air fuel ratio controller according to claim 1 or claim 2, in which the comparator is arranged to compare an estimated stored oxygen level with a plurality of thresholds when the detector detects rich breakthrough.

4. An open loop air fuel ratio controller according to claim 3, in which the controller is arranged such that when the model adjusting means adjusts the model the demand adjusting means does not adjust the air fuel ratio demand.

5. An open loop air fuel ratio controller according to

claim 4, in which the controller is arranged such that when the demand adjusting means adjusts the air fuel ratio demand the model adjusting means does not adjust the model.

6. An open loop air fuel ratio controller according to any one of the preceding claims in which the model adjusting means is arranged to adjust the model to reduce or increase a maximum oxygen storage value.

7. An open loop air fuel ratio controller according to any one of the preceding claims in which the detector is a heated exhaust gas oxygen sensor.

8. A method of open loop fuel control comprising the steps of

detecting rich breakthrough downstream of a catalyst;

estimating an oxygen storage level in the catalyst;

comparing the estimated oxygen storage level with a plurality of predetermined thresholds; and

adjusting the air fuel ratio demand in dependence upon the results of said comparing step and said detecting step.

9. A method of open loop fuel control according to claim 8, further comprising the step of

adjusting the model in dependence upon the results of said comparing step and said detecting step.

10. A method according to claim 8 or claim 9, in which adjusting the air fuel ratio demand comprises the sub step of

if the estimated oxygen storage level is less than a first predetermined threshold then the air fuel ratio demand is adjusted in a rich direction.

11. A method according to any one of claim 8 to 10, in which the model adjusting step and the air fuel ratio demand adjusting step are not performed if a rich breakthrough is detected and if the estimated oxygen level is greater than a second predetermined threshold and less than a third predetermined threshold.

12. A method according to any one of claim 8 to 11, in which adjusting the air fuel ratio demand comprises the sub step of if a rich breakthrough is detected and the estimated oxygen storage level is greater than a fourth predetermined threshold then the air fuel ratio demand is adjusted in a lean direction.

13. A method according to any one of claims 8 to 12, in which the model adjusting step is arranged to adjust the model such that a maximum value for the oxygen storage level is increased if a rich breakthrough is detected and if the estimated oxygen level is greater than the first predetermined threshold and less than the second predetermined threshold.

14. A method according to any one of claims 8 to 12, in which the model adjusting step is arranged to adjust the model such that a maximum value for the oxygen storage level is decreased if a rich breakthrough is detected and if the estimated oxygen level is greater than the third predetermined threshold and less than the fourth predetermined threshold.

15. A method according to any one of claims 11 to 14 wherein the first predetermined threshold is less than or equal to the second predetermined threshold and the second predetermined threshold is less than or equal to the third predetermined threshold.

16. A method according to any one of claims 12 to 14 wherein the first predetermined threshold is less than or equal to the second predetermined threshold and the second predetermined threshold is less than or equal to the third predetermined threshold and the third predetermined threshold is less than or equal to the fourth predetermined threshold.

17. An air fuel ratio controller substantially as herein described, with reference to the accompanying drawings.

18. A method of open loop fuel control substantially as herein described with reference to the accompanying drawings.

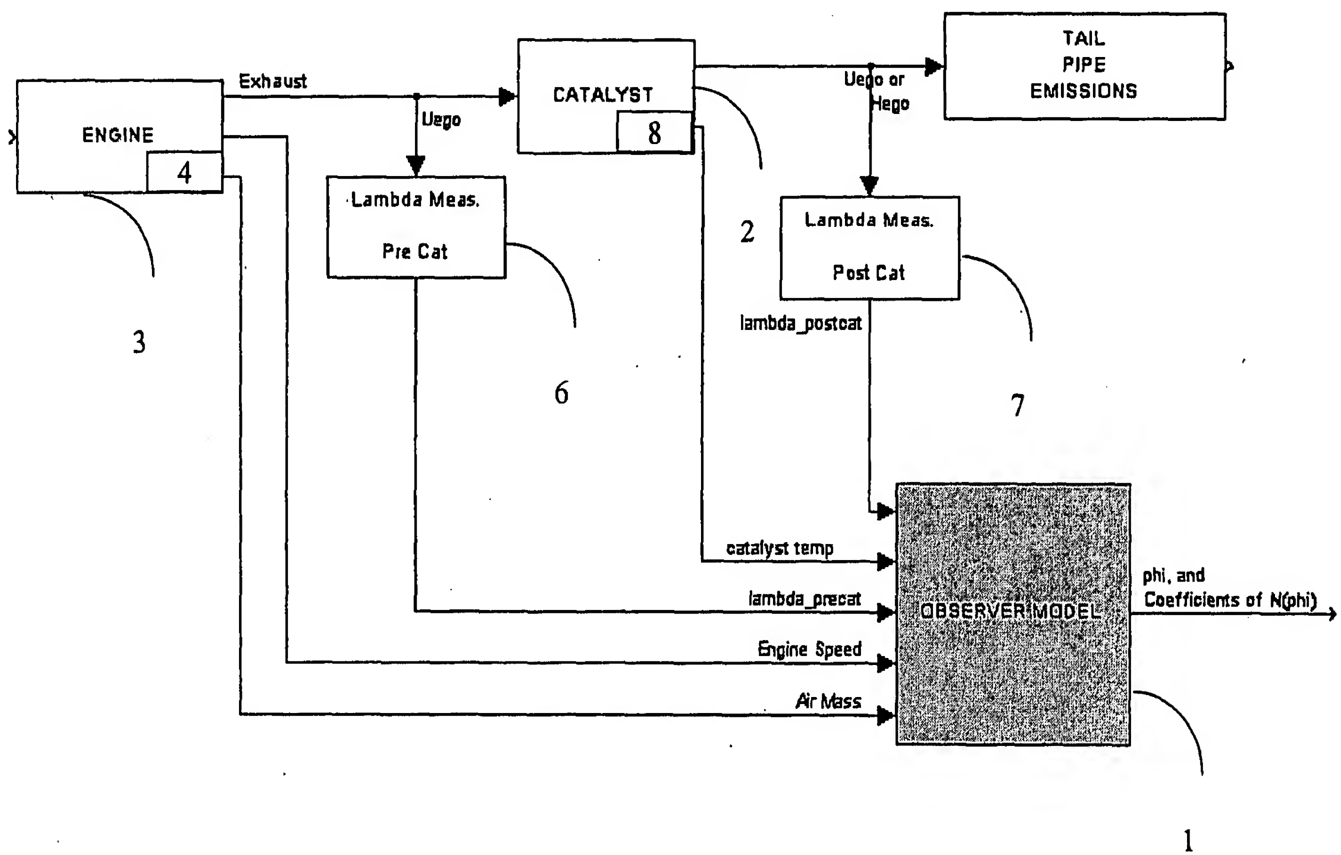
ABSTRACT

OPEN LOOP FUEL CONTROLLER

This invention relates to a method and apparatus for controlling the air-fuel ratio demanded by a fuel controller in order to maintain optimum performance of a catalytic converter. The invention provides an open loop fuel controller comprising a detector arranged down stream of a catalyst for detecting rich breakthrough; a catalyst model having an estimator for estimating a stored oxygen level in the catalyst; a comparator for comparing an estimated stored oxygen level with a plurality of predetermined thresholds; demand adjusting means for adjusting an air fuel ratio demand in dependence upon a received signal from said comparator and upon a received signal from said detector. A method of open loop fuel control is also provided.

Figure 5

Fig. 1



ENGINE
4
3
Exhaust
Uego
CATALYST
8
2
Lambda Meas.
Pre Cat
6
Uego or
Hego
TAIL
PIPE
EMISSIONS
Lambda Meas.
Post Cat
7
lambda_postcat
catalyst temp
lambda_precat
Engine Speed
Air Mass
OBSERVER MODEL
phi, and
Coefficients of N(phi)
1

Fig. 2

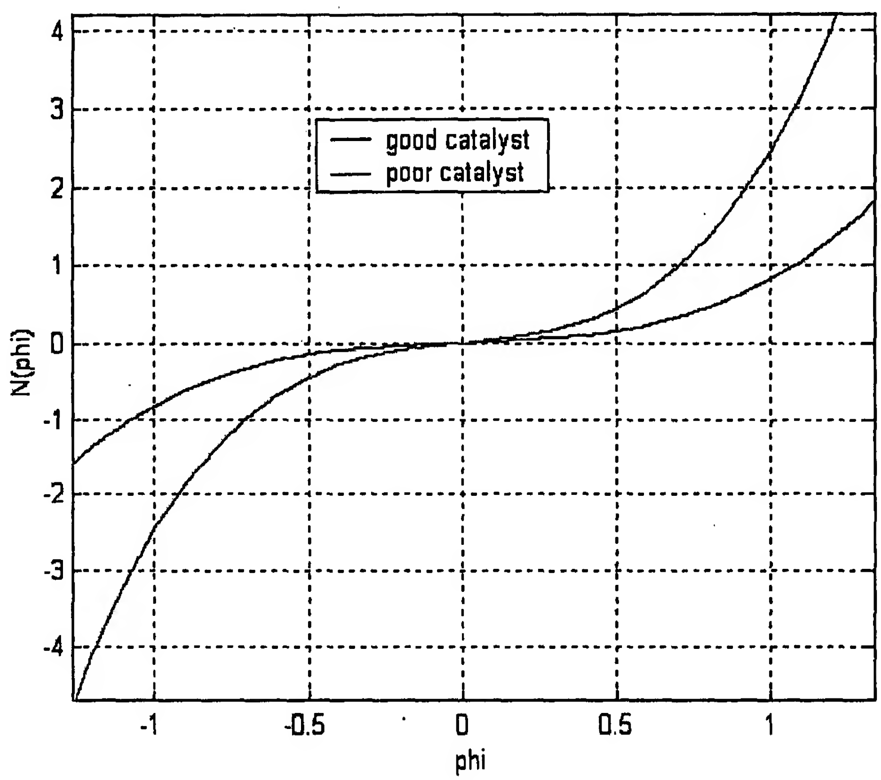
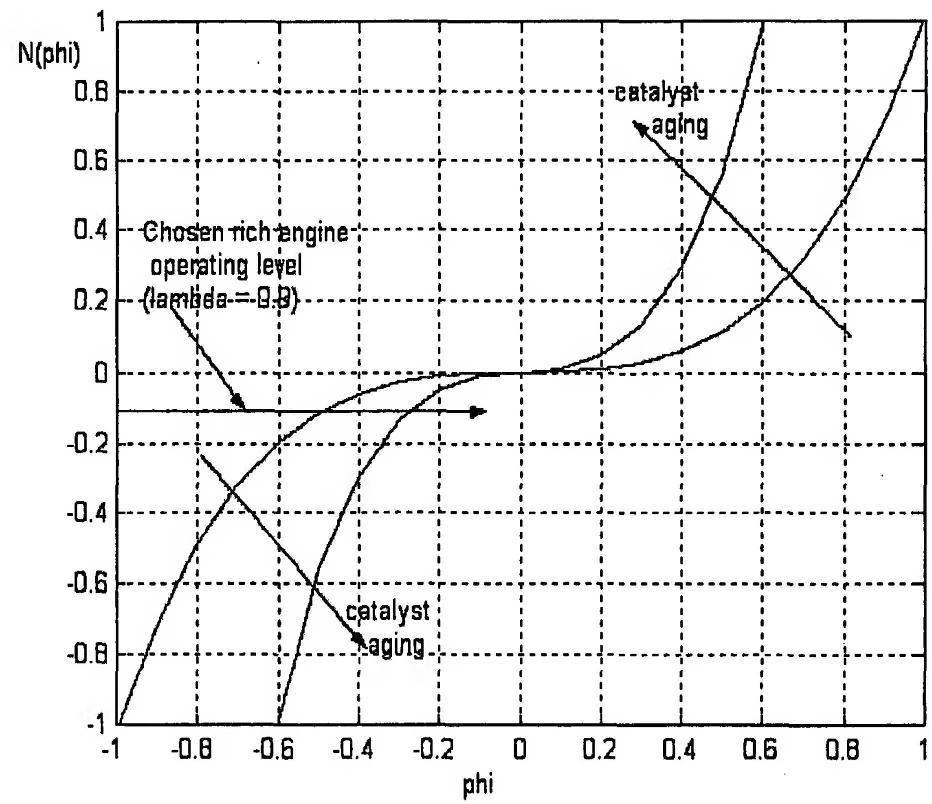
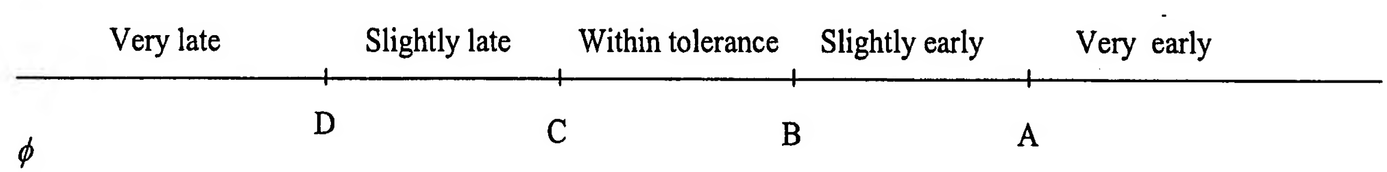


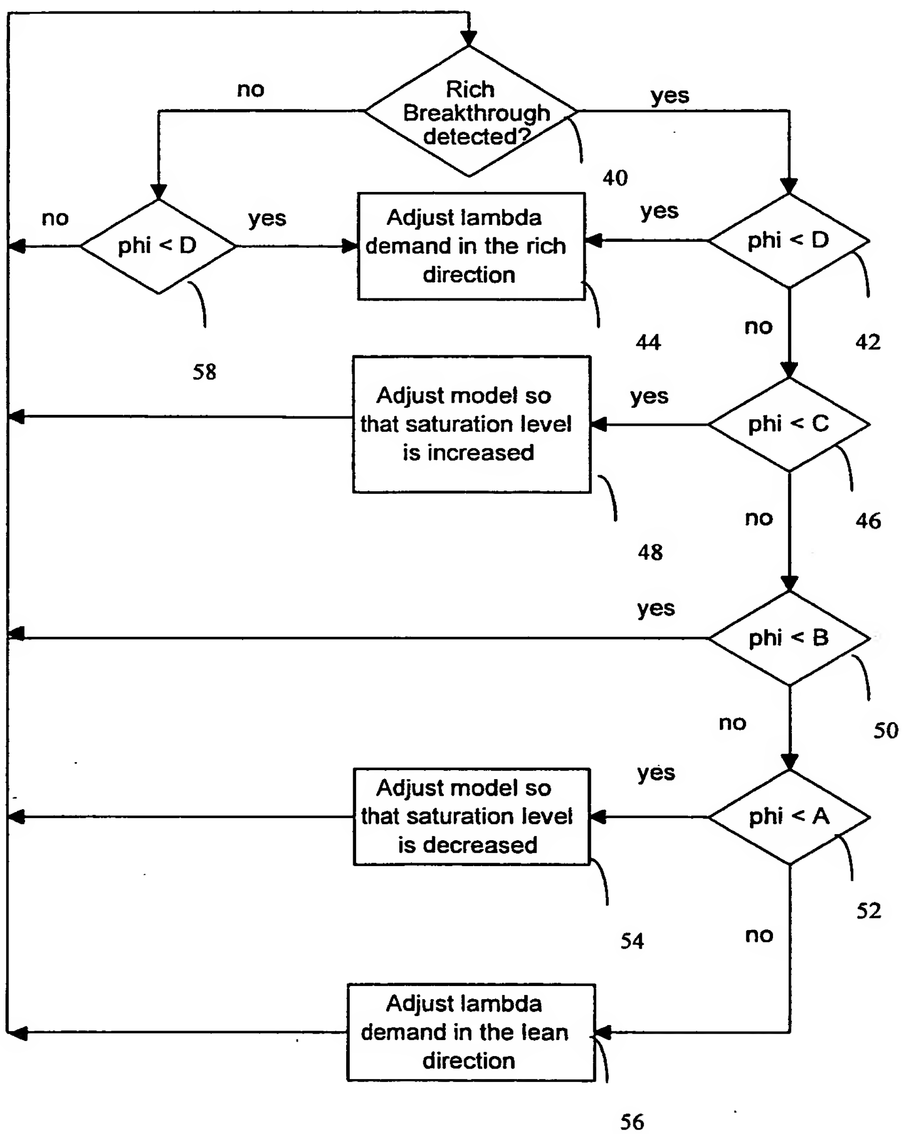
Fig.3



N(phi)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
phi
Chosen rich engine
operating level
(lambda = 0.9)
catalyst
aging
catalyst
aging

Value of ϕ when rich break through occurs





Rich Breakthrough detected?
40
no
yes
phi < D
58
no
yes
Adjust lambda demand in the rich direction
44
phi < D
42
yes
no
Adjust model so that saturation level is increased
48
phi < C
46
yes
no
phi < B
50
yes
no
Adjust model so that saturation level is decreased
54
phi < A
52
yes
no
Adjust lambda demand in the lean direction
56